Detection of Stellar Variability
in the Central Parsec of the Galaxy


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July 171993: 5th version

To be Submitted to the *Astrophysical Journal*

## ABSTRACT

We have searched for time variability of the stars in the central 1 pc region of the Galaxy through K-band imaging and photometry. On timescales ranging from 20 seconds to a week, no time variability greater than 0.1 mag was found for about five dozen sources in this region, including the components of IRS 16 and the anomalous high velocity outflow stars. On a timescale of one year, we found a new source near IRS 10E that had brightened by at least one magnitude and detected possible variability with amplitude $\sim 0.15$ mag in several other sources.

## 1. INTRODUCTION

Suffering from an extinction of about 30 magnitude at visual wavelengths, the center of our Galaxy is best studied at infrared and radio wavelengths. The presence of an infrared stellar cluster was first revealed by Becklin and Neugebauer (1968, 1975), who showed that the central 1 pc (= 25" for an assumed distance of 8 kpc) region contained more than a dozen discrete sources as well as extended emission at 2.2 $\mu$m and 10 pm. Since then, a number of high resolution near-infrared observations have been presented (Allen, H yland, & Jones 1983; Bailey, Hough, & Axon 1984; Rieke, Rieke, & Paul 1989; Tollestrup, Capps, & Becklin 1989; Simons, Hodapp, & Becklin 1990; Simon et al. 1990; DePoy & Sharp 1991; Eckart et al. 1992), which resulted in the discovery of more than 30 discrete sources in the central 25" region; many additional sources arc identified in the very high resolution images presented by Eckart et al. (1993).

Although most of the stars within a few parsecs of the Galactic center appear to be red giants (Becklin et al. 1978), some of which could be expected to show temporal variability, within the central parsec there is a change in the character of the population. Luminous blue supergiants may become dominant in this region as evidenced by a decrease in the depth of the CO absorption at 2.3 $\mu$m and by the presence of individual objects much bluer than the red giants (Rieke et al. 1989; Sellgren et al. 1990; Allen et al. 1983). Some of these blue stars show heavy mass loss in stellar winds (Krabbe et al. 1991). Elsewhere in the Galaxy and the Large Magellanic Cloud, stars of this type - referred to as Luminous Blue Variables (e.g., Humphreys 1989) - arc associated with recent episodes of massive star formation and are known to vary, However, present conditions in the central few parsecs of the Galaxy are very different from those under which stars are currently forming in the outer Galaxy, and other processes, such as stellar mergers (that might produce contact binaries with orbital rather than intrinsic variability y), or accretion onto stellar-mass black holes could produce objects similar in appearance to blue supergiants (Phinney 1989). in either case, detection and characterization of a pattern of time variability could improve our understanding of the Galactic center stars.

A search for such variability is possible with the new generation of infrared cameras using large detector arrays. Hailer and Rieke (1989) have searched for long-period variables within a $5' \times 5'$ region centered on the Galactic center at 2 $\mu$m and discovered 12 variables whose characteristics are consistent with those of Mira variables. However, their observations do not extend into the crowded central arcminute of the Galaxy. In this paper, we present the first results of a 2.2 $\mu$m search for variability of the stars within this central region. Our observations span timescales ranging from 20 seconds to one week, and include follow up observations taken a year after the initial observations.

## 2. OBSERVATIONS AND RESULTS

A series of high resolution images of the Galactic center was acquired on the NASA Infrared Telescope Facility (IRTF) 3-m telescope on 1991 July 24 through 30 (UT), using the ProtoCA M 62x58 InSb camera (Toomey et al. 1990). We employed a $K$-band (2.2 $\mu$m) falter for all observations reported here, The plate scale was measured to be O" .347 ± O" .008 pixel$^{-1}$ from a comparison of our results with the astrometric results by Tollestrup et al. (1989) and Rosa et al. (1992) and the field of view of each frame was 20".1 x 21".5.

Exposures were limited to 0.5 -1.0 sec by the requirement that the array did not saturate at the bright star IRS 7. These short exposures were: coadded so that the total integration time of each frame was 20 sec.. Identical observation of the sky were made after offsetting the telescope to a sky position, 180" east and 65$''$ south of Sgr A, where the 2 $\mu$m brightness is low. Two regions of the Galactic center was imaged: one is roughly centered on 1 RS 16 and the other is centered 5" north of it. Both frames include the IRS 16 complex on different portions of the array detector, therefore, systematic effects due to non-uniformity of the array, even after flatfielding, can be checked by comparing the photometry of two separate data sets. In fact, our relative photometry for sources that are included in both central and northern frames is consistent, In order to improve the photometric precision, we also dithered the observed positions ($\sim$ 2" ) after each 20 sec exposure frame. Each frame is used separately for the aperture photometry described later.

Seeing conditions were critical to our observations because of the high density of bright stars in the images (cf. Fig. 1 ). The seeing was monitored by measuring the FWHM of IRS 7: IRS 7 is a bright supergiant and can be considered to be a point-like source for the purpose of seeing estimation. The seeing was mediocre and variable (0".7 -- 2".3) during the first four nights. However, it was excellent and stable (0".4 - 1".4, typically 0".8) during the last three nights, A seeing of 2" is acceptable for relative photometry of the isolated sources (like IRS 9). However, the central crowded region requires a seeing better than 1" for photometry, since the typical separation between the discrete sources is $\sim 1''$. As a result, accurate relative photometry for the crowded sources (including the components of IRS 16) is limited to the last three nights of data, On 1992 June 24 (UT), similar images were obtained with the same instrument on the same telescope, using the procedure described above. The plate scale was measured to be the same as that in the last year with an uncertainty of less than 1 %. The seeing was mediocre ( 1".0- 2" .0), similar to that for the first three nights of the 1991 run. We used this data set to search for any variability on a one-year timescale, by comparing it to data obtained with similar seeing in 1991.

### *2.1* High *Resolution Images*

The images were reduced by subtracting the adjacent sky frame from the on-source frame and dividing by a normalized sky flat frame. One of the best seeing images, a mosaic of two frames (integration time = 20 see), is shown in Figure 1a, with a logarithmic identification map in Figure lb. This is one of the highest resolution images of the Galactic center ever taken and agrees very well with the results of DePoy and Sharp (1991) who present images taken with a similar plate scale of O".3 pixel$^{-1}$, covering a similar field of view ($\sim$ 20"). We note that the source associated with an anomalous high velocity outflow, AHH (Allen, Hyland, & Hillier 1990; Forrest et al. 1987), is double; it is also resolved but not mentioned by DePoy axial Sharp (1 991), Another less studied outflow source, AHH NW, is also seen in our image as a multiple source. Very recently, Eckart et al. (1993) have presented O" .15 resolution images of the central 20" region, A number of the IR sources, in particular IRS 16 and 13, have been resolved into multiple sources. However, the Eckart et al. picture does not affect the main results of this paper. Their data show that IRS 1W, our principal photometric standard, is not a multiple source, although it does show evidence for low-level extended emission.

The high quality photometry possible with good seeing images such as shown in Fig. 1a allowed us to set stringent limits on short term variabilit y on the last three days of the 1991 run. In addition, we can summarize our imaging results on the IR cluster as follows:

(1) IRS 16 has at least 5 distinct components: NE, SW-W, NW, C, and CC. Eckart et al. (1992, 1993) show that the region south and east of IRS 16 SW-W contains a number of additional components.

(2) There is no clear discrete 2 $\mu m$ source at the position of the compact radio source Sgr A*; however, we would have not been sensitive to the low-level emission identified at this position by Eckart et al. in their processed images.

(3) IRS 1 has a very complex structure: there ate at least 3 sources (W, NE, and SE) and additional extended emission. Other multiple or extended sources include AHH, AHH NW, 12N, 13, 7, 29, 33, 14 SW, and 10E.

(4) In addition to the 10 sources previously identified by Rosa et al. (1992), IRS 15, A7, A12, and A13 and probably IRS 33 and 35 have 1 $\mu m$ counterparts in the deep CCD images of Rosa et al.

### *2.2 Photometric Results: One Week Timescale*

On each preprocessed 20 sec exposure frame, synthetic aperture photometry was carried out for the discrete sources, using the IRAF photometry package APPHOT(X). Table 1 shows the photometric results as well as the positions (relative to IRS 7) of the previously known and newly identified sources. 'I'he newly identified sources are labelled Al through A24; standard nomenclature is adopted for the previously known sources. The position of each source was determined from the best seeing images by using IRAF IMCNTR as well as by eye for several sources in very crowded regions. An aperture radius of 0".88 (2.5 pixels) was used for the photometry, without subtraction of the background component, because a) our main objective was to search for variability of point sources; and b) the background is difficult to define in this complex region. We therefore have shown an estimation of the contribution of the background flux for each source in the last column of 'l'able I; for example, if the background contribution is 50 %, the star is 0,7 mag fainter than identified in the Table, and the limit on the variability in magnitudes is twice the tabulated value. IRS lW, the 2nd brightest source in this region, was used as the standard star for the relative photometry. It is unlikely that all these sources would vary in synchrony with IRS 1 W, so the lack of variability y in any of the sources justifies the use of IRS1W as the standard. However, because IRS 1W is slightly extended and identified as a (potentially variable) He I outflow source (Krabbe et al. 1991), it may ultimately not be the best secondary standard for this type of study. Although the average seeing in the last three nights was pretty good, there were several out-bursts of poor seeing. in order to obtain the best photometry, we therefore rejected the poorer seeing ( > 1".23) data for the statistical calculation in the last three nights. No seeing selection was made for the first four nights.

On one week timescale, the "light curves" for 57 sources, with only one possible exception, do not show clear variability other than slight changes which correlate with the seeing conditions. In Figure 2 are shown the light curves of selected sources for all seven nights in 1991 plus one night in 1992, for the best nights (5-7) in 1991, and for a one-hour continuous period on night 6. The only evidence suggestive of variability on short timescales is that of IRS 16SW-W, which showed a marginal but systematic dimming by 0.1 mag on nights 5-7 (see Fig 2b). This cannot be taken as definitive variability, however, because of the low amplitude and of the very complex structure of this region (Eckart et al. 1993).

### *2.2 Photometric and Imaging Results: One Year After*

In Figures 3a and 3b are compared two images of the Galactic center obtained with an interval of about one year: Fig. 3a is an average of 53 frames obtained on the 2nd night of the 1991 run (FWHM = 1".49) and Fig. 3b is an average of 19 frames obtained in the 1992 run (FWHM = 1".46). *Two images* are *very similar except that the appearance of the IRS 10 complex (10E and 10 W) is* very different between *the 1991 and 1992 images.* in the 1991 data, IRS 10E and 10W were clearly separated from each other even under mediocre seeing conditions, while in the 1992 data, IRS 10E and 10W are bridged by a single extended component. The 1992 peak in the IRS 10 complex does not coincide with the old IRS 10E position, but lies about 0".7 west. Figure 4 is a cut at position angle 26° South of East of the images through IRS 10E and 10W with a 1" N-S width, The solid line represents the 1992 data, the broken line the 1991 data, and the dotted line their difference. It is clear that the position of the new peak is not coincident with IRS 10E. We identify this peak to be a new source in the Galactic center IR cluster and call it IRS

10(new), Because IRS 10(new) is within the extended IRS 10 complex, photometry is very difficult. However, its peak flux increased by at least a factor of 3 between the two dates. The *K* magnitude of this source in 1992 derived from a difference of two images (see below) is $\sim$ 10.4.

In Fig. 3c is shown a subtracted image (Fig. 3b minus Fig. 3a). The most prominent features are: 1) a roughly round (stellar-like) positive residual which corresponds to IRS 10(new) mentioned above; and 2) very strong but distorted positive and negative residuals which correspond to IRS 7. The latter is due to a slight difference of the shape of the point spread function of the two images, despite that fact that the FWHM of two images arc almost the same; this effect is pronounced because of the great brightness of IRS 7. Also one notices that: 3) roughly round positive residuals are seen toward IRS 9, 12N, and 28, which might suggest that these three sources are variables.

In order to remedy the seeing effect (i.e., the slight difference of the PSF), we present in Table 2 aperture photometric results (aperture radius = 0".88) of relatively bright and isolated sources which compare the 2nd night data in 1991 with the 1992 data after selecting the data with seeing between 1".25 and 1".80. Four sources (IRS 7, 9, 12N, and 28) show evidence for brightening of 0.1 to 0.2 msg. For 9, 12N, and 28, the apparent variability is seen in the light curve (Fig, 1) as well. The photometric results confirm the possibility that IRS 9, 12N, and 28 are variables, as suggested by the image subtraction. This result appears true even if we use a larger aperture (radius = 1".40) for the photometry, which is less affected by the seeing conditions, Although the variability of these three sources plus IRS 7 therefore appears real, our data above are not compelling evidence, because of the possibility y of subtle systematic effects. However, we note that Eckart et al. report independent evidence for the variability of IRS 9 and IRS 12N, so it seems likely that these two sources at least are truly variable.

We discuss the types of variability which might be expected for stars at the Galactic center below.

## 3. DISCUSSION

### 3.1 *LBV-Type* Variability?

Of more than 30 near-infrared sources in the central 1 pc (25") region of the Galaxy, the nature of a few is known: IRS 7 is classified as an M2 supergiant and IRS 11, 12N, and 19 are suggested to be M5–7 giants, mostly based on the CO absorption feature at 2.3 $\mu$m (Sellgren et al. 1987; Treffers et al. 1976). The IRS 16 complex, situated nearest to Sgr A*, is most peculiar, because of its blue color and very weak 2.3 $\mu$m CO feature (Rieke et al. 1989; Sellgren et al. 1987). IRS 16NE, C, NW, and SW-W are known to be compact (less than 50- 200 AU), and they are not star clusters (Simons et al. 1990; Simon et al, 1990). Their absolute $K$ magnitudes range from -7 to -9. This complex could be the $10^7$ $L_\odot$ UV source, of effective temperature $\sim$35,000 K which is required to ionize the gas in the Galactic center (Becklin, Gatley, & Werner 1982; Lacy et al. 1982; Davidson et al. 1992). A plausible explanation of the complex is that these are luminous early type stars (Rieke et al. 1989; Allen et al. 1990),

This explanation is strongly supported by the recent discovery (Krabbe et al. 1991) of *high* velocity He I 2.06 $\mu$m line emission sources, a number of which are identified with the discrete components of the infrared sources including IRS 16. The outflow speed and mass loss rate inferred from these observations are significant, 500-1000 km $s^{-1}$ and up to $10^{-4} M_{\odot}\ yr^{-1}$, respectively. This result suggests that these luminous blue stars are undergoing a heavy mass loss. On the other hand, Werner, Stauffer, & Becklin (1990) and Werner et al. (1993) have demonstrated that these sources do *not* have strong the He II 3.09 $\mu m$ line characteristics of the Wolf-Rayet stars.

Krabbe et al. (1991) have suggested that these objects are Luminous Blue Variables (LBVs), that is, evolved, very luminous, unstable blue supergiants suffering significant mass loss (Humphreys 1989). in fact, the strongest He I star in the Galactic center region, AHH, is shown from its infrared spectrum to resemble the helium-rich LBVs seen in the LMC (Allen et al. 1990).

Although such LBVs are noted for sudden outbursts with a brightness change of several magnitudes, they also show smaller amplitude variability y on a range of timescales. There is a rough positive correlation between the variability amplitude and timescale (Lamers 1987; Humphreys 1989). With the timescale of 20 seconds to a week, we expect variations only of order of 0.1 mag or less. In contrast, with a timescale of 1 year, we would expect moderate variations in LBVS. For example, the LBV, AG Car has been reported to show variations with an amplitude up to 0.8 mag at $K$ during 11 months period (Whitelock et al. 1983).

None of the He 1 stars we observed (except perhaps IRS 16 SW-W) show evidence for short term variability greater than 0.1 mag; however, the current data does not rule out lower amplitude variability and is thus consistent with identification of these sources as

LBVs. Most of the He I stars show no evidence for variability on a 1 year timescale, with limits typically ~ 0.1 msg. The strongest He I stars, AHH and IRS 13 show less than 0.05 mag variability on this timescale. The photometry of these sources is particularly reliable because they are isolated and bright. Therefore, the significant mass-loss seen in the He I stars is not accompanied by the pronounced LBV-type variability,

One important exception could be IRS 9. IRS 9 is a He I star and, although it is identified by Eckart et al. (1993) as a red star, its spectrum does not show CO absorption (Rieke et al. 1990). Thus, it could well be a luminous early type supergiant with peculiar colors. If the variability reported here and by Eckart et al. is verified by further observations, IRS 9 could in fact be an LBV-type variable,

### 3.2 Binary- Type Variability y ?

Stars in the Galactic center are expected to have a fraction of ellipsoidal and eclipsing variable binaries considerably enhanced over the ~2% characteristic of stars in the solar neighborhood. The 2% figure is appropriate for local O stars, similar to the luminous blue stars in the Galactic center: in the complete sample of 67 O stars in Garmany et al. (1980), 19 are confirmed spectroscopic binaries, and 1 (1.5%) is eclipsing; in the complete sample of 195 0 stars in Gies (1987), 31 are confirmed spectroscopic binaries (36 more arc suspected), and 4 (2%) are confirmed eclipsing. Since in both samples about 1/3 of the stars were only poorly studied, the 2% figure is probably a lower limit, and might be as high as 3%. There are two processes which are expected to lead to an enhancement of this binary fraction in the Galactic center.

First, the inner 0.2 pc (5 arcsec) of the Galactic center could be dominated by stellar mergers and disruptions (Phinney 1989). Those calculations by Phinney were done for turnoff-mass stars, but the probability that a star has a collision while on the main sequence is nearly independent of the star's mass for $M > 3M_{\odot}$ —as is easily understood by noting that on the upper main sequence, $L \propto M^3$, so the lifetime $t_{ms} \propto M/L \propto M^{-2}$ and the gravitationally-focussed cross-sections for collision and tidal capture $\sigma \propto MR \propto M^2$, so $\sigma t_{ms}$ is independent of $M$. This upper main sequence collision probability is about 0.1 times that for a star of the turnoff mass $1.0M_{\odot}$. Tidal capture resulting from a collision is expected to produce binaries so close that ellipsoidal variations would be significant, ancl eclipses probable (i.e. type EB variables),

Second, binary stars born in the Galactic center region will have their orbits shrunk ('hardened') by encounters with passing single and binary stars (e.g. Hut 1983, 1992). in the solar neighborhood, some 30% of OB stars are in spectroscopic binaries (Garmany et al. 1980, van Albada 1985, Gics 1987) with semi-major axes in the range which in the inner 0.3 pc (8 arcsec) of the Galaxy would be hardened during their lifetime almost to contact binaries. These hardened binaries would also appear as eclipsing or ellipsoidal variables. This process also should operate in globular clusters (see the review by Hut et al. 1992), and is seemingly confirmed by the discovery by Mateo et al. (1990) that three of the blue stragglers in the globular cluster NGC 5466 are eclipsing binaries, with periods between 0,3 and 0.5 days and minima of depth $\sim 0.3$ mag. The supergiant blue stars which we observed in the Galactic center have much larger radii than the stars Mateo et al. observed in globular clusters. Thus the minimum periods of contact binaries among our stars would be much longer, $\gtrsim 4$ d.

Even if none of these enhancing processes operate, we would still expect to detect primordial eclipsing binaries at the local 2% rate (see above). The several semi-detached eclipsing OB stars known in the solar neighborhood —e.g. QZ Carinae (Leung, Moffat, & Seggewiss 1979) with $P = 6$ d, AV = 0.2 and RY Scuti (Giuricin & Mardirossian 1982) with $P = 11.1$ d and AV = 0.7, show large ellipsoidal variations which would have been detectable by our survey at the Galactic center. Our non-detection rate of short term variability among $\sim$ 1 dozen blue stars at the Galactic center is not in conflict with these ideas but suggests that the rate of binary formation and hardening is not much greater than expected.

### 3.3 Mira-type Variability ?

Hailer and Rieke (1989) conducted an 1 R imaging search of the central 5' x $5'$ region of the Galaxy with an array detector; however, this search for long-period variables did not include the crowded central one arcmin of the Galaxy. Of the 154 stars surveyed by Hailer and Rieke, 12 stars are found to be variable. Those stars have apparent $K$ magnitudes from 10.5 to 12.0 and amplitudes of $K$ magnitude variation over a 4 months interval range from 0.2 to 1.0 msg. These amplitudes and variation timescales are characteristic of Miras (Feast et al. 1982). Furthermore, the bolometric magnitudes of these variables, corrected for extinction, are similar to those of the Miras observed through Baade's window (Glass and Feast 1982). It is noteworthy that the apparent $K$ magnitude of the newly identified star, IRS 10(new), is similar to the average $K$ mag of these suspected Miras. The amplitude of $K$ magnitude variation, $\gtrsim 1$ mag, is slightly larger than those of Miras (0.4 - 0.9 mag; Feast et al. 1982), however. Of other sources which show possible long-term variability (IRS 9, 7, 12N, and 28), IRS 12N is classified as an M7 111 star (Tollestrup et al. 1989; Sellgren et al. 1987) and might also be a Mira.

### 3.4 *Nature of IRS 10*

The IRS 10 complex (including 10E and 10W) shows a He I outflow and is situated in the 'northern arm" of ionized gas. IRS 10W is one of the brightest 10 $\mu$m sources in the central region (Becklin and Neugebauer 1975; Gezari et al. 1985; Rieke et al. 1989). It also has the largest intrinsic polarization at 1O $\mu$m in this region (Aitken et al. 1986). IRS 10E is shown by Rieke et al. to be a red giant with strong CO bands, while IRS 10W may be an early-type supergiant. Note that the He I emission associated with IRS 10 arises from a region to the west of IRS 10W (Krabbe et al. 1991) and is not related to IRS 10(new).

IRS 10 is resolved into IRS 10E and 10W in the near-infrared maps by Allen, Hyland, Jones (1983), Bailey et al. (1984), Forrest, Pipher, Stein (1986), Rieke et al. (1989), Tollestrup et al. (1989), Simon et al. (1990), DePoy & Sharp (1991), all of which show morphology similar to our 1991 data. However, this sparsely sampled data show that the relative brightness of these components has varied over the past 8 years; on some occasions one of the two (usually 10E) appears brighter than the other, while at other times they are comparable to one another. Given that the source IRS 10(new) would not have been resolved from 10E in these earlier data sets, these results suggest that this source has shown previous evidence of variability. Therefore, although the large magnitude change has occurred in the last one year, there have also been variations in brightness in the past. in 1993 May, Neugebauer (private communications) imaged the IRS 10 region at 2.2 $\mu$m, using an InSb array on the 200 inch telescope, The source again appeared as the two components, 1013 and 10W, indicating that the brightness of 10(new) has declined.

What is the nature of IRS 10(new)? The historic pattern of apparent variability cited above would seem to rule out an exotic explanation, such as a microlensing event, and there is no evidence for an He 1 outflow which would be suggestive of an LBV at this position, Although other possibilities (e.g., a binary star) cannot be excluded, the magnitude and pattern of variability y of IRS 10(new) are consistent with identification as a luminous Mira variable.

Note that Hailer & Rieke identified 12 Miras of brightness comparable to IRS 10(new) in a 5' x 5' area centered on the Galactic center. Given that the space density of stars varies as $r^{-2}$ in this region, we would expect ~1 such variable within the approximately 0.5 x 0.5 arcmin region we have observed. Identification of IRS 10(new) as a Mira is consistent with these statistical expectations.

## 4. CONCLUSION

We have conducted a search for time variability of the stars in the central 1 pc region of the Galaxy through $K$-band imaging and photometry with an array detector. On relatively short timescales ranging from 20 seconds to a week, no definite time variability greater than 0.1 mag was found for about five dozen sources in this region, including the components of IRS 16 and the anomalous high velocity outflow st ars. The lack of short time variability among the Galactic center sources is not inconsistent with the idea that they are luminous blue variables or ellipsoidal and eclipsing variable binaries.

On a timescale of one year, we found that a new source near IRS 10E had brightened by at least one magnitude. This object has the characteristics of a Mira variable. We also found possible variability on a one-year timescale with amplitude $\sim 0.15$ mag in several other sources. One of these, IRS 9, is associated with a He I outflow and has a featureless near-infrared spectrum. It is a candidate for identification as a variable early-type supergiant, perhaps an LBV. The other He I stars are constant to within 0.1 mag over a one-year timescale. This suggests that the mass loss seen in these stars is not accompanied by marked I,IIV-type variability.

We thank G. Neugebauer for observing the IRS 10 region for us and M. Rieke, G. Rieke, and M. Jura for useful discussions. M. '1'. is supported by a National Research Council Associateship. This research was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under contract with National Aeronautics and Space Adrninist ration.

REFERENCES

Aitken, D. K., Roche, P. F., Bailey, J. A. Briggs, G. P., & Thomas, J. A. 1986, MNRAS, 218, 363

Allen, D. A., Hyland, A. R., & Hillier, D. J. 1990, MNRAS, 244, 706

AlAen, D. A., Hyland, A. R., & Jones, T. J. 1983, MNRAS, 204, 1145

Bailey, J., Hough, J. H., & Axon, D. J. 1984, MNRAS, 208, 661

Becklin, E. E., Gatley, I., & Werner, M. W. 1982, ApJ, 258, 135

Becklin, E. E., Matthews, K., Neugebauer, G., & Winner, S. P. 1978, ApJ, 219, 121

Becklin, E. E., & Neugebauer, G. 1968, ApJ, 151, 145

Becklin, E. E., & Neugebauer, G. 1975, ApJ, 200, L71

Davidson, J. A., Werner, M. W., Wu, X., Lester, D. F., Harvey, P. M., Joy, M., & Morris, M. 1992, ApJ, 387, 189

DePoy, D. L., & Sharp, N. A. 1991, AJ, 101, 1324

Eckart, A., Genzel, R., Hofmann, R., Sams, B. J., & Tacconi-Garman, L. E. 1993, ApJ, 407, L77

Eckart, A., Genzel, R., Krabbe, A., Hofmann, R., van der Werf, P. P., & Drapatz, S. 1992, Nature, 355, 526

Feast, M. W., Robertson, B. S. C., Catchpole, R. M., Lloyd Evans, T., Glass, I. S., & Carter, B. S. 1982, MNRAS, 201, 439

Forrest, W. J., Pipher, J. L., & Stein, W. A. 1986, ApJ, 301, L49

Forrest, W. J., Shure, M. A., Pipher, J. L., & Woodward, C. E. 1987, in The Galactic Center, ed. D. C. Backer (NewYork: AIP), 153

Garmany, C.D. Conti, P.S. & Massey, P. 1980, ApJ 242, 1063

Gezari, D. Y. et al. 1985, ApJ, 299, 1007

Gies, R.. 1987, ApJS 64, 545

Giuricin, G. & Mardirossian, F. 1982 in IAU Symp. 99, Wolf- Rayet Stars: Observations, Physics, Evolution, eds. C.W.H. de Loore & A.J. Willis (Dordrecht: Reidel), 383

Glass, I. S. & Feast, M. W. 1982, MNRAS, 198, 199

Hailer, J. W., & Rieke, M, J. 1989, in The Center of the Galaxy, IAU Symposium No. 136, ed. M, Morris (Kluwer, Dordrecht), 487

Humphreys, R. M. 1989, in Physics of Luminous Blue Variables, eds. K. Davidson et al. (Dordrecht: Kluwer), 3

Hut, P. 1983, ApJ, 272, L29

Hut, P. et al. 1992, PASP, 104, 981

Krabbe, A., Genzel, R., Drapatz, S., & Rotaciuc, V. 2991, ApJ, 382, L19

Lacy, J. H., Townes, C. H., & Hollenbach, D. J. 1982, ApJ, 262, 120

Lamers, H. J. G. L. M. 1987, in Instabilities in Luminous Early Type Stars (Dordrecht: Reidel), 99

Leung, K. -C., Moffat, A. F. J., & Segewis, W. 1979, ApJ, 231, 742

Mateo, M., Harris, H. C., Nemec, J., & Olszewski, E. W. 1990, AJ, 100,469

Phinney, E. S. 1989, in IAU Symposium No. 136, The Center of the Galaxy, ed. M. Morris (Kluwer, Dordrecht), 543

Rieke, G. H., Rieke, M. J., & Paul, A. E. 1989, ApJ, 336, 752

Rosa, M. R., Zinnecker, H., Moneti, A., & Melnick, J. 1992, A&A, 257, 515

Sellgren, K., Hall, I). N. B., Kleinmann, S. G., & Scoville, N. Z. 1987, ApJ, 317, 881

Sellgren, K., McGinn, M. T., Becklin, E. E., & Hall, D. N. B. 1990, ApJ, 359, 112

Simon, M., Chen, W. P., Forrest, W. J., Garnett, J. D., Longmore, A. J., Gauer, T., & Dixon 1990, ApJ, 360, 95

Simons, I). A., Hodapp, K. -W., & Becklin, E. E. 1990, ApJ, 360, 106

Tollestrup, E. V., Capps, R. W., & Becklin, E. E, 1989, AJ, 98, 204

Toomey, D. W., Shure, M., Irwin, E. M., & Ressler, M. E. 1990, SPIE Conf. on Instrumentation in Astronomy VII, 69

Treffers, R. R., Fink, U., Larson, H. P., & Gautier, T. N. 1976, ApJ, 209, L115

van Albada, T.S. 1985, in Birth and Evolution of Massive Stars and Stellar Groups, eds. W. Boland & H. van Woerdin (Dordrecht: Reidel), 8

Werner, M. W., **Stauffer,** J. R., & Becklin, **E. E.** 1990, in Evolution of the Universe of Galaxies, ed. R. G. Kron (ASP **Conf. Proc.** 10,) 167

Werner, M. W., **Stauffer,** J. R., **Becklin,** E. E., & Lee, T. 1993, in preparation

**Whitelock, P.** A., Carter, B. S., Roberts, G., **Whittet,** D. C. B., & **Baines,** D. W. T. 1983, MNRAS, 205,577

Table 1

RELATIVE PHOTOMETRY[a] OF GALACTIC CENTER SOURCES

| IRS[b] | Δ R.A. (″) | Δ Dec. (″) | 7 nights Mean (mag) | 7 nights σ (mag) | 3 nights[c] Mean (mag) | 3 nights[c] σ (mag) | 1 night[d] Mean (mag) | 1 night[d] σ (mag) | BG[e] (70) |
|---|---|---|---|---|---|---|---|---|---|
| 1W[f] | 543 | −5.26 | 0 | — | 0 | — | 0 | — | — |
| 1NE | 7.19 | −4.11 | — | | 0.933 | 0.027 | 0.911 | 0.024 | 10-25 |
| 1SE | 7.37 | −6.13 | — | — | 1.140 | 0.030 | 1.130 | 0.028 | 10-25 |
| 2S | -3.87 | −10.29 | — | — | 1.394 | 0.037 | 1.401 | 0.035 | >50 |
| 5 | 8.80 | 4.12 | 1.533 | 0.049 | 1569 | 0.033 | 1.556 | 0.028 | 25-50 |
| 6E | −5.34 | −4.91 | 1.090 | 0.041 | 1.120 | 0.028 | 1.130 | 0.030 | 10-25 |
| 7 | 0.00 | 0.00 | −1.826 | 0.065 | -1.885 | 0.023 | −1.874 | 0.016 | <10 |
| 9 | 5.58 | −12.17 | 0.435 | 0.037 | 0.398 | 0.018 | 0.407 | 0.008 | 10-25 |
| 10E | 8.67 | −1.58 | — | | 1.125 | 0.032 | 1.106 | 0.025 | 25-50 |
| 10W | 6.73 | −0.59 | — | — | 1.329 | 0.028 | 1.344 | 0.020 | 25-50 |
| 12N | −3.50 | −12.70 | 0.563 | 0.035 | 0.570 | 0.024 | 0.588 | 0.022 | 10-25 |
| 12S | −3.70 | −14.29 | — | — | 1.025 | 0.038 | 1.049 | 0.034 | 10-25 |
| 13E | −3.22 | −7.34 | 0.527 | 0.034 | 0.550 | 0.024 | 0.551 | 0.020 | 10-25 |
| 14NE | 0.70 | −13.90 | 0.770 | 0.071 | 0.818 | 0.043 | 0.829 | 0.042 | 10-25 |
| 14SW | −0.34 | −14.87 | — | — | 0.895 | 0.113 | 0.873 | 0.031 | 10-25 |
| 15 | 1.28 | 5.84 | 0.600 | 0.024 | 0.592 | 0.028 | 0.575 | 0.015 | 10-25 |
| 16NE | 2.85 | −4.62 | 0.138 | 0.039 | 0.175 | 0.017 | 0.168 | 0.014 | 10-25 |
| 16C | 1.22 | −5.30 | — | | 0.546 | 0.029 | 0.551 | 0.021 | 25-50 |
| 16NW | 0.09 | −4.56 | — | | 0.8?3 | 0.028 | 0.887 | 0.025 | 25-50 |
| 16SWW | 1.03 | −6.88 | — | | 0' 24? | 0.045 | 0.313 | 0.020 | 25-50 |
| 21 | 2.33 | −8.45 | — | | 1.090 | 0.036 | 1.086 | 0.025 | 25-50 |
| 28 | 10.58 | −11.65 | 1.035 | 0.035 | 1.029 | 0.029 | 1.049 | 0.028 | 10-25 |
| 29 | -1.71 | −4.25 | — | — | 0343 | 0.022 | 0.852 | 0.023 | 25-50 |
| 30 | −6.33 | 0.18 | 1.473 | 0.051 | !508 | 0.037 | 1.496 | 0.045 | 10-25 |
| 32 | 10.57 | −4.66 | 1.253 | 0.049 | !279 | 0.034 | 1.269 | 0.026 | 25-50 |
| 33 | 0.7 | −8.74 | — | | 0.834 | 0.041 | 0.844 | 0.028 | 25-50 |
| AHH | 6.79 | −12.75 | 1.657 | 0.060 | 1.704 | 0.031 | 1.713 | 0.028 | 25.50 |
| Seeing | — | — | 1″.27 | 0″.39 | 0″.84 | 0″.19 | 0″.64 | 0″.14 | — |

[a] Photometry relative to IRS 1W ($K$ = 8.7 mag; Tolletrup et al. 1989).
[b] Source identification. New sources are designated like IRS A1.
[c] Data with the seeing less than 1″.23 during the 5th - 7th nights.
[d] Data with the seeing less than 1″.23 in the 7th night.
[e] Estimated background contribution in the photometry.
[f] Standard star for the photometry.

Table 1 (cont.)

| IRS[b] | AILA. (″) | Δ Dec. (″) | 7 nights Mean (mag) | 7 nights σ (mag) | 3 nights[c] Mean (mag) | 3 nights[c] σ (mag) | 1 night' Mean (mag) | 1 night[d] σ (mag) | BG[e] ( % ) |
|---|---|---|---|---|---|---|---|---|---|
| 6W | −7.88 | -4.18 | 1.496 | 0.045 | 1.492 | 0.052 | 1.491 | 0.059 | 10-25 |
| A1 | −6.31 | -15.82 | — | — | 1.931 | 0.035 | 1.941 | 0.033 | 25-50 |
| A2 | −5.76 | 3.83 | — | — | 1.827 | 0.034 | 1.s12 | 0.039 | 25-50 |
| A3 | -4.55 | 5.74 | — | — | 2.034 | 0.042 | 2.023 | 0.04-4 | 25-50 |
| 34 | -4.05 | −3.96 | — | — | 1.525 | 0.025 | 1.229 | 0.033 | 25-50 |
| A4 | -3.37 | 4.08 | — | — | 1.703 | 0.025 | 1.690 | 0.018 | >50 |
| A5 | -2.94 | 5.77 | — | — | 1.745 | 0.035 | I.728 | 0.017 | >50 |
| 3 | -2.43 | −1.81 | — | — | 1.689 | 0.041 | 1.698 | 0.032 | 25-50 |
| A6 | -2.25 | −14.95 | — | — | 1.597 | 0.030 | 1.580 | 0.019 | 25-50 |
| A? | -2.24 | 2.96 | — | — | 1.526 | 0.028 | 1.518 | 0.027 | 25-50 |
| A8 | −1.20 | −3.16 | — | — | 1.408 | 0.067 | 1.411 | 0.070 | 25-50 |
| 20 | −1.14 | −11.13 | — | | 1.362 | 0.031 | 1.364 | 0.012 | 25-50 |
| A9 | −0.45 | 6.17 | — | — | 1.491 | 0.046 | 1.4s3 | 0.048 | 25-50 |
| A10 | 4.43 | −11.97 | — | — | 1.492 | 0.025 | 1.494 | 0.023 | >50 |
| A11 | −0.24 | -7.84 | — | | 1.053 | 0.054 | 1.103 | 0.0-40 | >50 |
| A12 | 0.00 | 2.99 | — | — | 1.544 | 0.044 | 1.534 | 0.0-45 | 25-50 |
| A13 | 0.17 | 4.75 | — | — | 1.552 | 0.04? | 1.570 | 0.036 | 25-50 |
| A14 | 0.50 | 3.67 | — | — | 1.551 | 0.037 | 1.532 | 0.029 | 25-50 |
| A!5 | 1.56 | −12.38 | — | — | 1.675 | 0.02s | 1.671 | 0.038 | 25-50 |
| 7SE | 1.82 | −1.12 | — | — | 1.494 | 0.100 | 1.425 | 0.083 | 25-50 |
| 35 | 3.04 | -6.97 | | — | 1.260 | 0.050 | 1.229 | 0.033 | 25-50 |
| A16 | 3.51 | −17.27 | — | — | — | — | — | — | — |
| A17 | 3.58 | −8.12 | — | — | 1.579 | 0.052 | 1.556 | 0.042 | 25-50 |
| A18 | 3.69 | 1.60 | — | — | 2.076 | 0.034 | 2.064 | 0.024 | 25-50 |
| Al? | 3.88 | −13.00 | — | — | 1.835 | 0.039 | 1.850 | 0.028 | >50 |
| A20 | 4.39 | -048 | — | — | 2.022 | 0.032 | 2.009 | 0.023 | >50 |
| A2: | 4.69 | -9.22 | — | — | 1.937 | 0.037 | 1.930 | 0.026 | >50 |
| A22 | 5.35 | −2.64 | — | — | 2.088 | 0.034 | 2.082 | 0.030 | >50 |
| A23 | !!.42 | −14.87 | — | — | 2.126 | 0.033 | 2.151” | 0.025 | >50 |
| A24 | 11.64 | −1.96 | — | | 1.538 | 0.044 | 1.S26 | 0.044 | 25-50 |
| Seeing | — | — | 1″.27 | 0″.39 | 0″.84 | 0″.19 | 0″.54 | 0″.14 | — |

Table 2

RELATIVE PHOTOMETRY OF GALACTIC CENTER SOURCES - COMPARISON WITH AN INTERVAL OF ABOUT ONE YEAR

| IRS | 1991[a] Mean (mag) | 1991[a] $\sigma$ (mag) | 1992[b] Mean (mag) | 1992[b] $\sigma$ (mag) | diff.[c] Mean (mag) | diff.[c] $\sigma$ (mag) |
|---|---|---|---|---|---|---|
| 1W (raw) | 9.04 | 0.10 | 9.04 | 0.05 | 0.00 | 0.11 |
| 7 | -1.79 | 0.04 | -1.94 | 0.02 | -0.15 | 0.04 |
| 16SW-W | 0.11 | 0.04 | 0.15 | 0.03 | 0.04 | 0.05 |
| 16NE | 0.12 | 0.03 | 0.15 | 0.02 | 0.03 | 0.04 |
| 16C | 0.27 | 0.07 | 0.29 | 0.03 | 0.02 | 0.08 |
| 9 | 0.44 | 0.03 | 0.30 | 0.02 | -0.15 | 0.04 |
| 13 | 0.52 | 0.03 | 0.53 | 0.02 | 0.01 | 0.04 |
| 12N | 0.55 | 0.04 | 0.40 | 0.02 | -0.15 | 0.04 |
| 15 | 0.61 | 0.02 | 0.66 | 0.03 | 0.05 | 0.04 |
| 33 | 0.63 | 0.09 | 0.63 | 0.06 | 0.00 | 0.11 |
| 16NW | 0.65 | 0.07 | 0.63 | 0.04 | -0.02 | 0.08 |
| 29 | 0.71 | 0.04 | 0.70 | 0.03 | -0.01 | 0.05 |
| 14NE | 0.72 | 0.05 | 0.74 | 0.03 | 0.02 | 0.06 |
| 14SW | 0.76 | 0.06 | 0.81 | 0.07 | 0.05 | 0.09 |
| 1NE | 0.78 | 0.07 | 0.81 | 0.04 | 0.03 | 0.08 |
| 12S | 0.85 | 0.06 | 0.82 | 0.04 | -0.03 | 0.07 |
| 1SE | 0.93 | 0.09 | 0.98 | 0.07 | 0.05 | 0.11 |
| 28 | 1.03 | 0.05 | 0.86 | 0.0? | -0.17 | 0.05 |
| 6E | 1.07 | 0.03 | 1.13 | 0.03 | 0.05 | 0.04 |
| 32 | 1.22 | 0.03 | 1.16 | 0.04 | -0.06 | 0.05 |
| 30 | 1.48 | 0.04 | 1.56 | 0.04 | -0.08 | 0.05 |
| 5 | 1.52 | 0.04 | 1.48 | 0.06 | -0.04 | 0.07 |
| AHH | 1.63 | 0.04 | 1.63 | 0.03 | 0.00 | 0.05 |
| Seeing | 1″.51 | 0″.14 | 1″.54 | 0″.11 | ··· | ··· |

Photometry relative to IRS 1W. Data with the seeing between 1″.25 and 1″.80.

[a] The 2nd night of 1991 run (1991 July 24).

[b] The 1992 run (1992 June 23).

[c] The difference of the 1991 and 1992 data.

Figure Captions

**Fig.** 1

(a) One of the best seeing images of the central 24" of the Galactic center **mosaiced** of two **frames,** (b) and an identification image in logarithmic scale. The plate scale was 0".35 pixel-l.

Fig. 2

Light curves of selected sources in the Galactic center: (a) during all seven nights in 1991 and one night in 1992, (b) during three nights in 1991 with **sub-arcsecond** seeing, and (c) during about an hour on the 6th night in 1991. Magnitudes are relative to IRS **1W.** Raw signal of IRS 1 W and seeing measured as **FWHM** of IRS 7 are also shown.

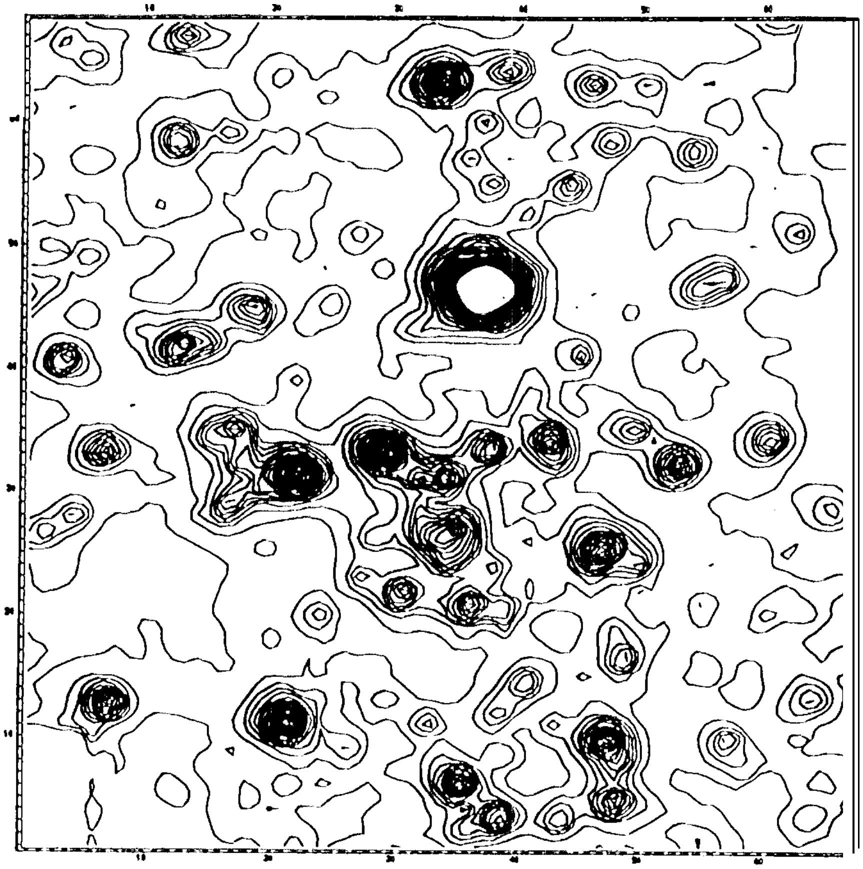
Fig. 3

(a) Average of seeing selected **(1".2** - 1".8) **images** on the 2nd night in the 1991 run, (b) the one in the 1992 run, and (c) subtracted image (Fig. 4a minus Fig. 4b). Note the appearance of a new source near IRS 10E, called **10(new).**

Fig. 4

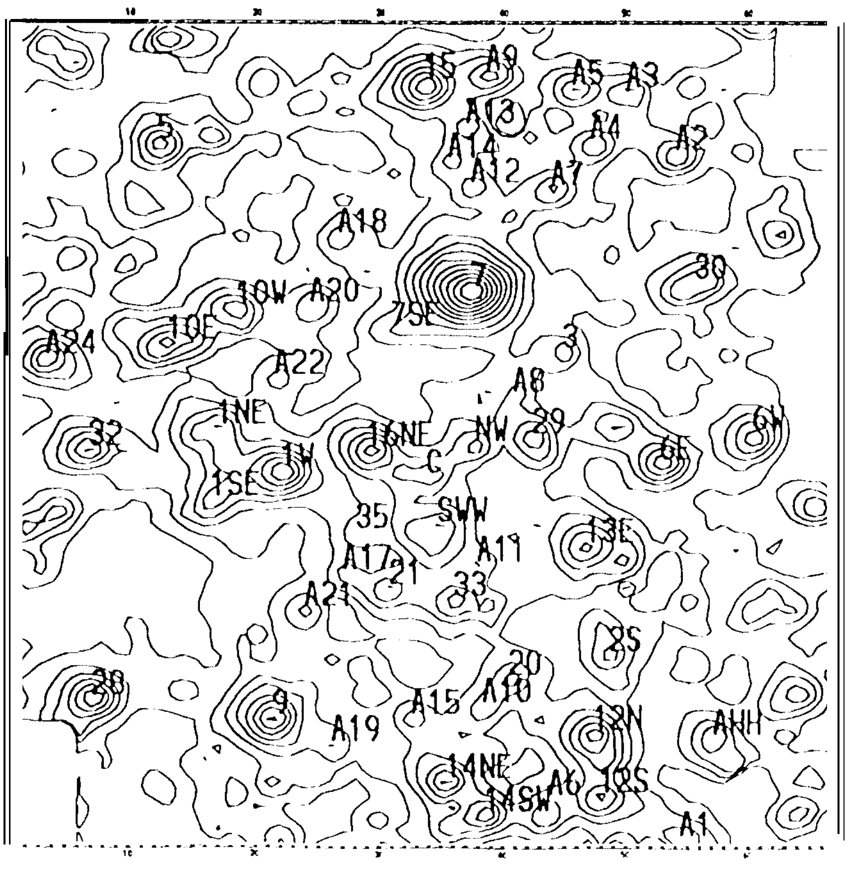
A spatial cut of the images through the peak of a new source near IRS 10E: solid line represents the 1992 data, broken line the 1991 data, and dotted line their difference. The cut direction is **P.A.** = 26° South of East and the width of the cut is 1" (3 pixels).

papfigatrimc:



contoured from 35. to 1400., interval= 35.
NOAO/IRAF V2.10EXPORT etamura@c1 Sun 18:29:05 27-Jun-93

papfigatrimmagc:



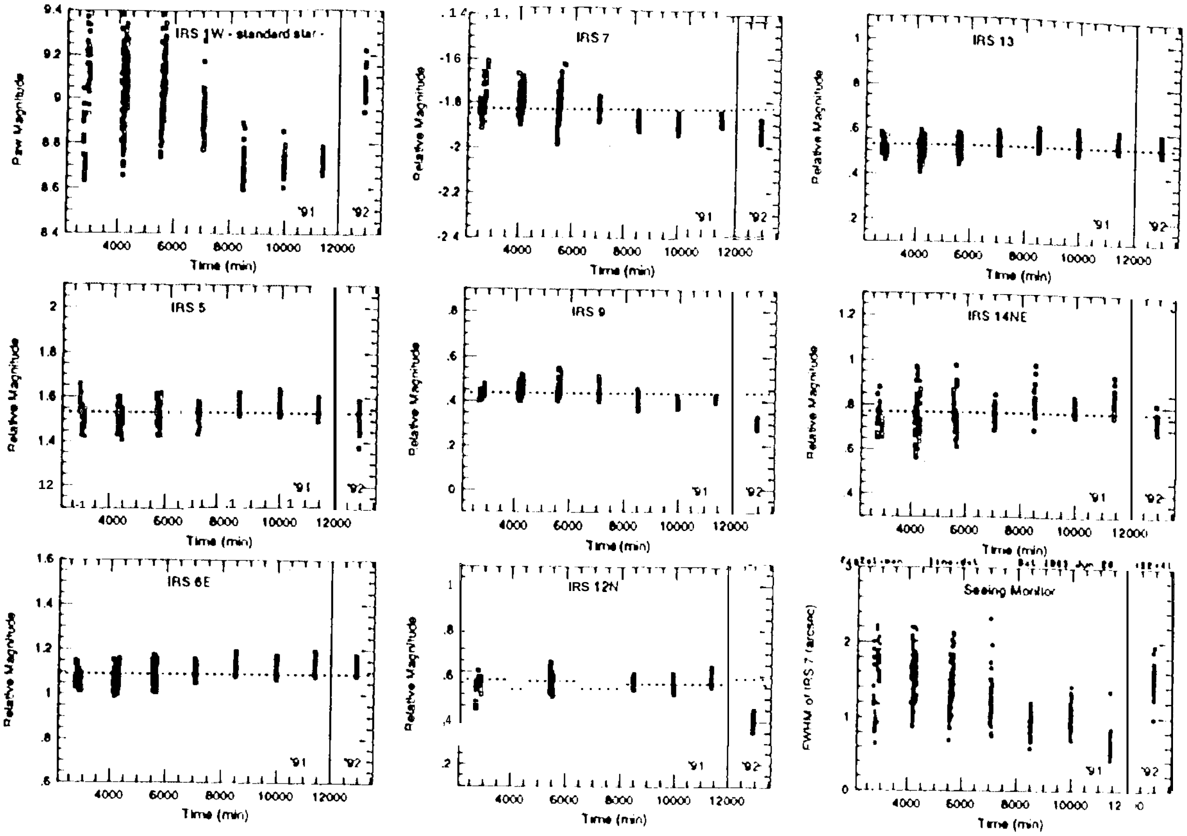
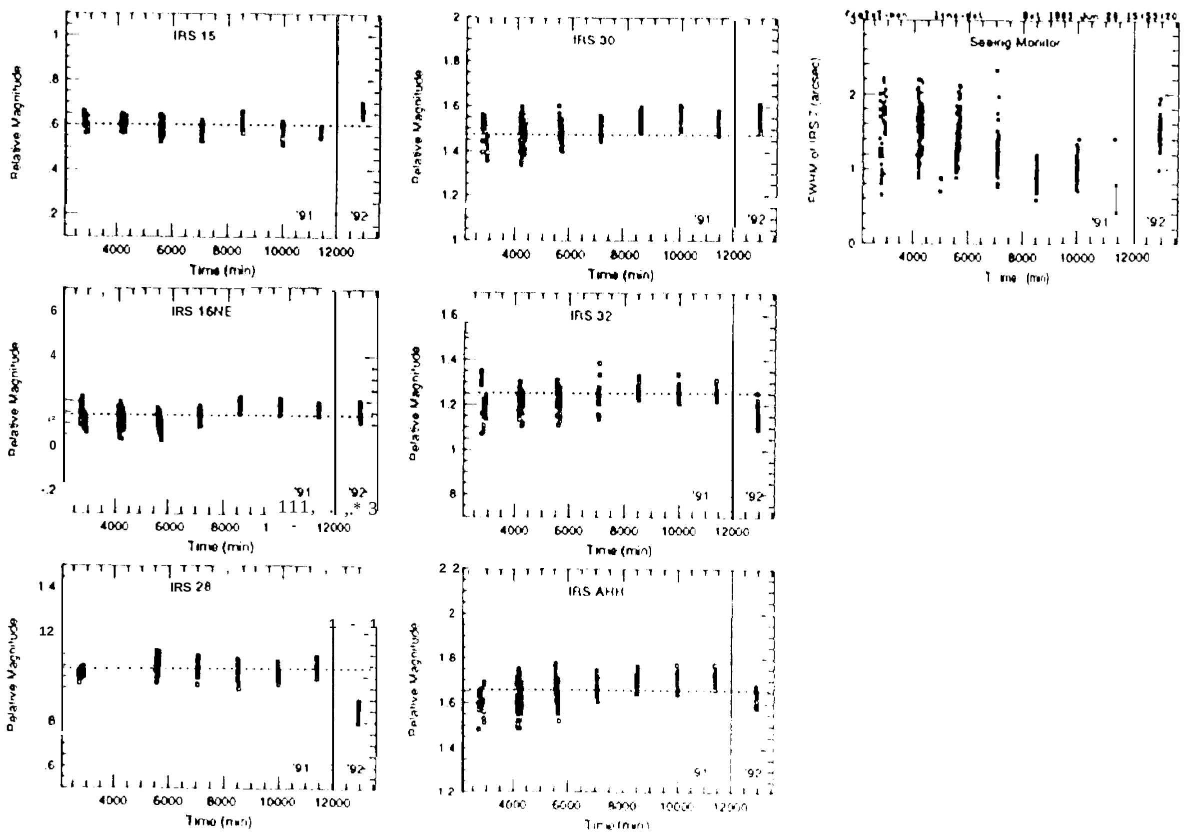

IRS 1W - standard star -
Raw Magnitude
Time (min)
IRS 7
IRS 13
IRS 5
IRS 9
IRS 14NE
IRS 6E
IRS 12N
Seeing Monitor
FWHM of IRS 7 (arcsec)
Relative Magnitude
'91
'92

Fig 2a 1/2


IRS 15
IRS 30
Seeing Monitor
IRS 16NE
IRS 32
IRS 28
IRS AHH
Relative Magnitude
Time (min)
'91
'92

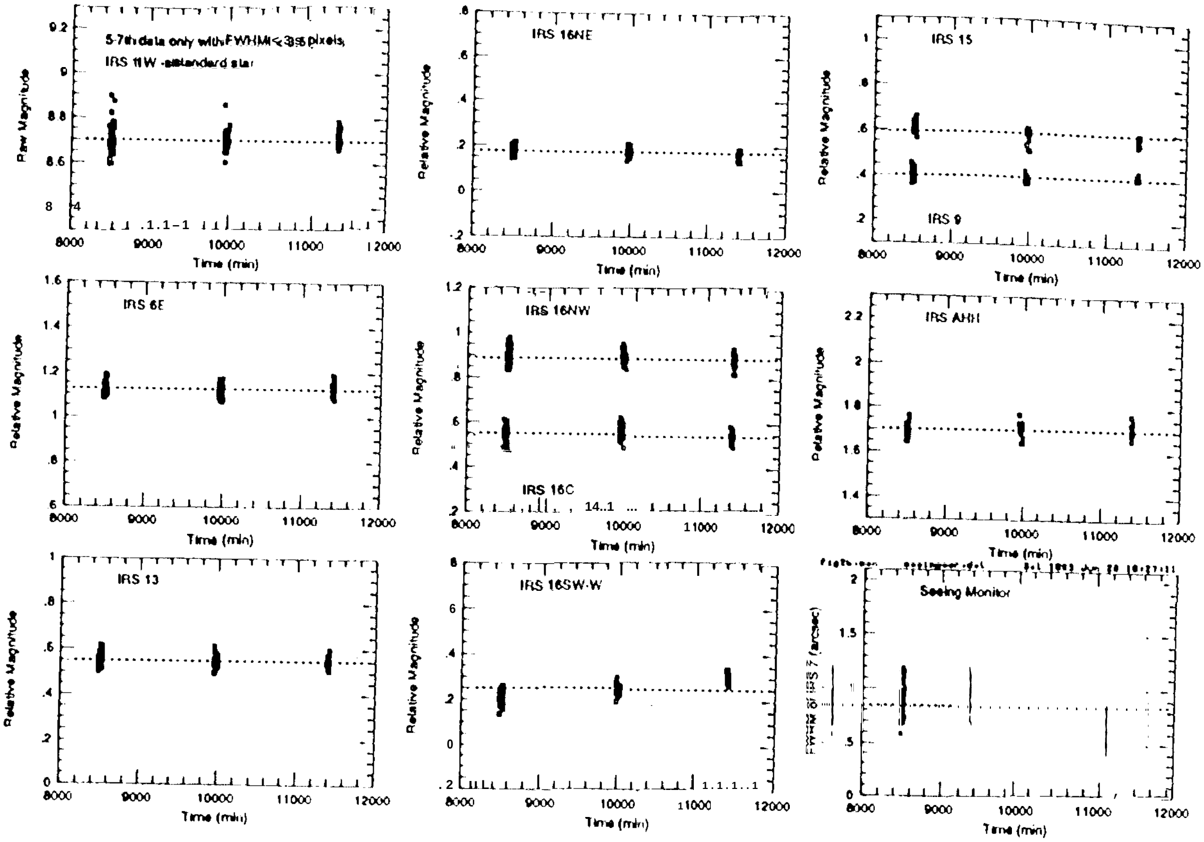
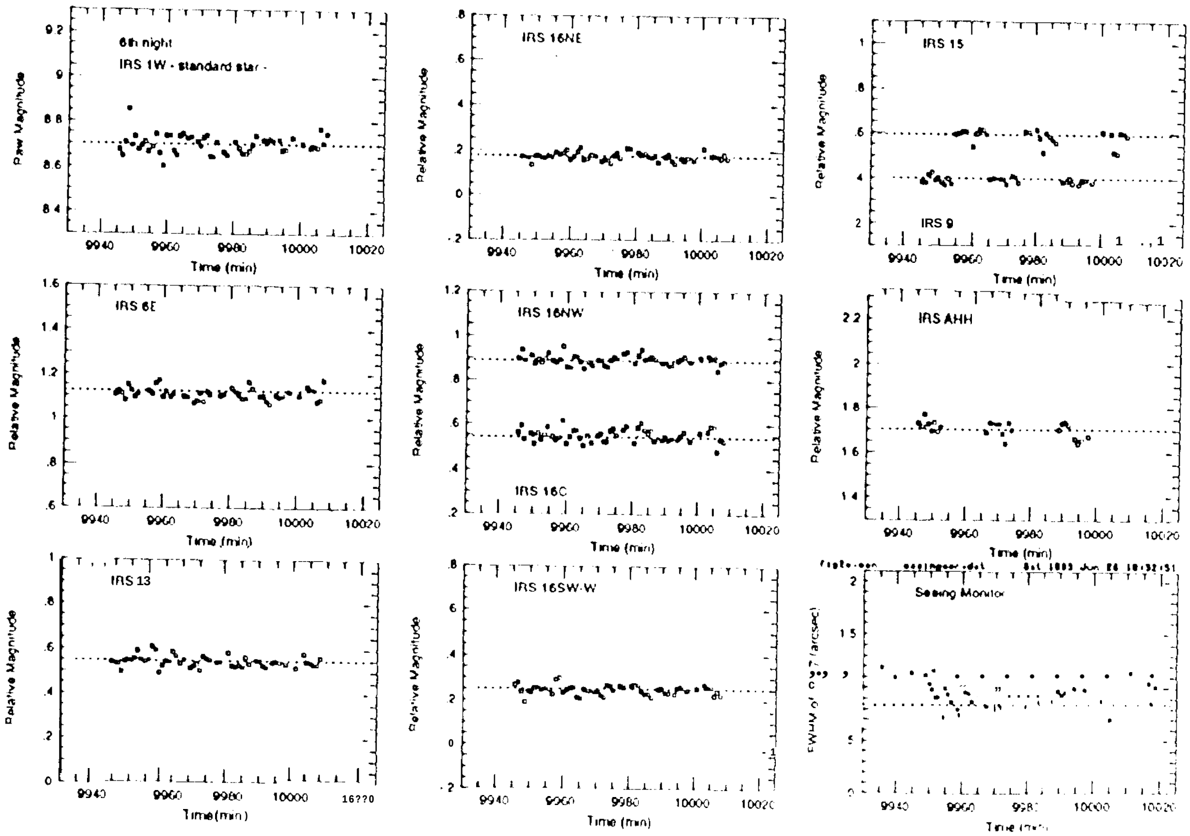
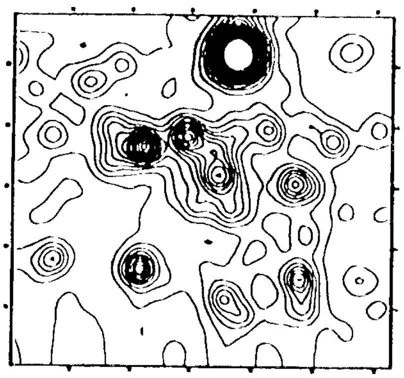

5-7th data only with FWHM<3.5 pixels,
IRS 11W - standard star
Raw Magnitude
Relative Magnitude
Time (min)
IRS 16NE
IRS 15
IRS 9
IRS 6E
IRS 16NW
IRS 16C
IRS AHH
IRS 13
IRS 16SW-W
Seeing Monitor
FWHM of IRS 7 (arcsec)

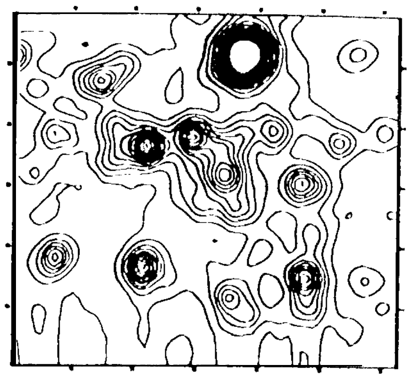
*Fig. 2b*


6th night
IRS 1W - standard star -
Raw Magnitude
Relative Magnitude
Time (min)
IRS 16NE
IRS 15
IRS 9
IRS 6E
IRS 16NW
IRS 16C
IRS AHH
IRS 13
IRS 16SW-W
Seeing Monitor

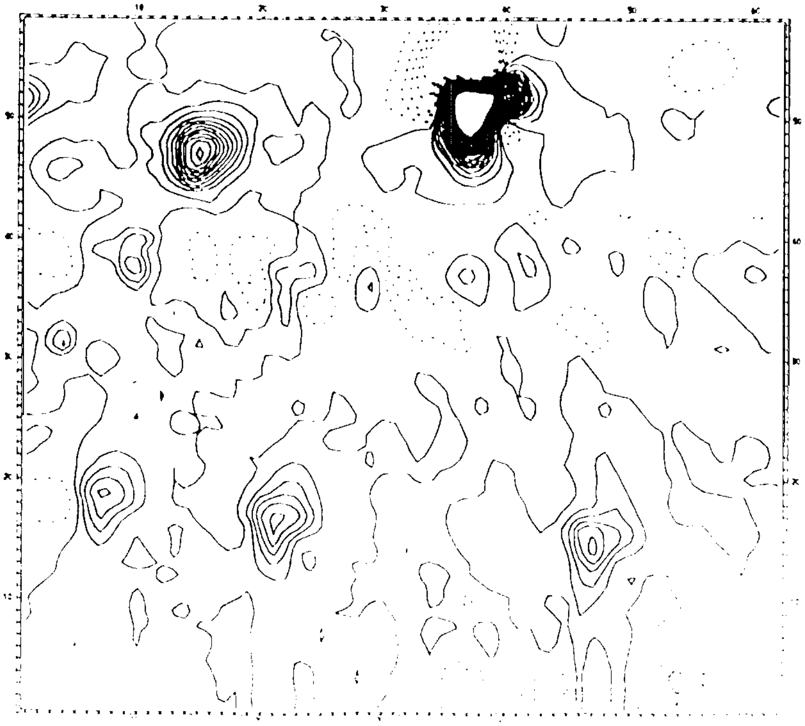
1991/07/25

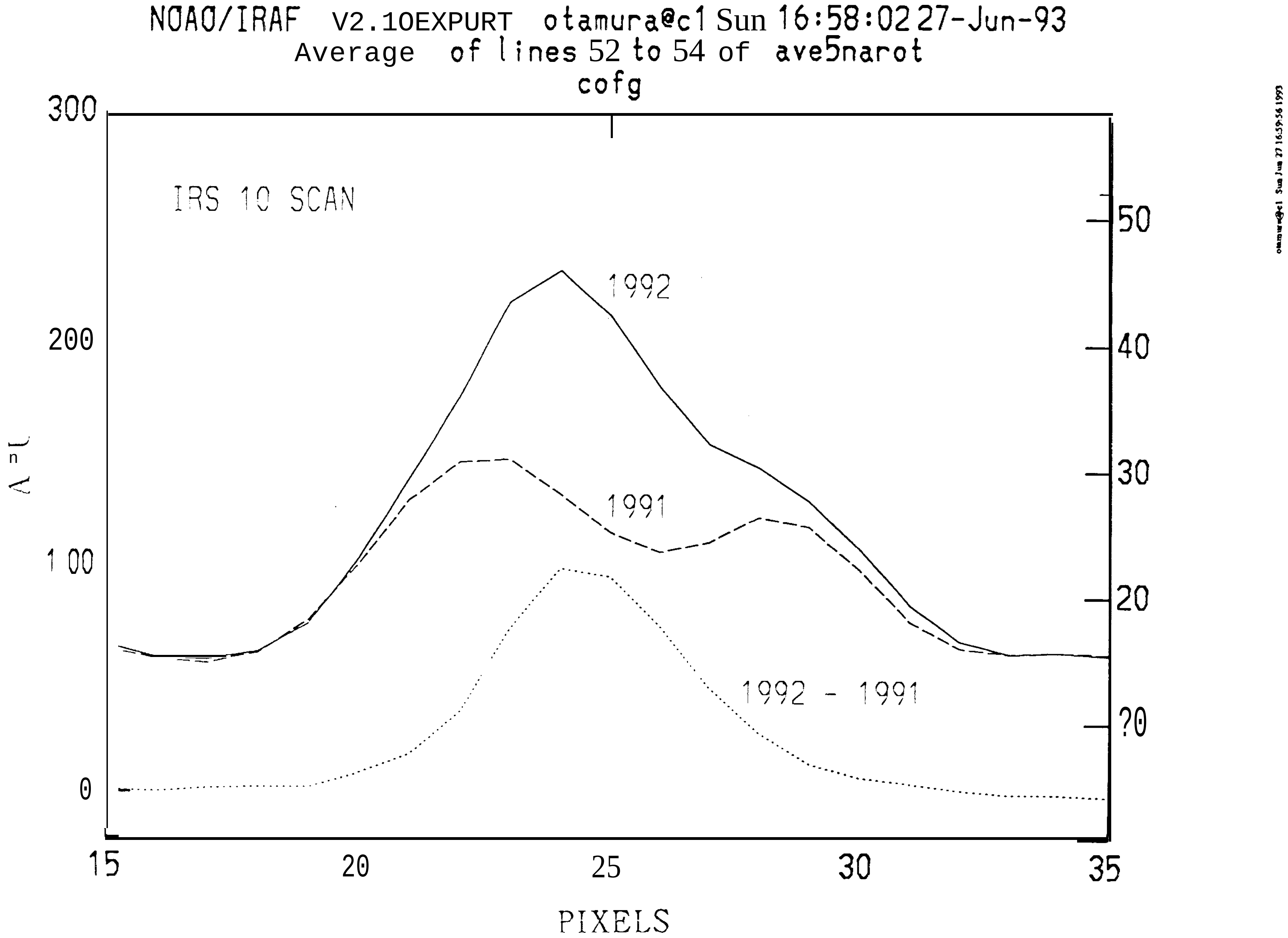


1992/06/24



1992 - 1991




NOAO/IRAF V2.10EXPURT otamura@c1 Sun 16:58:02 27-Jun-93
Average of lines 52 to 54 of ave5narot
cofg
IRS 10 SCAN
1992
1991
1992 - 1991
PIXELS
omamura@c1 Sun Jun 27 16:59:56 1993